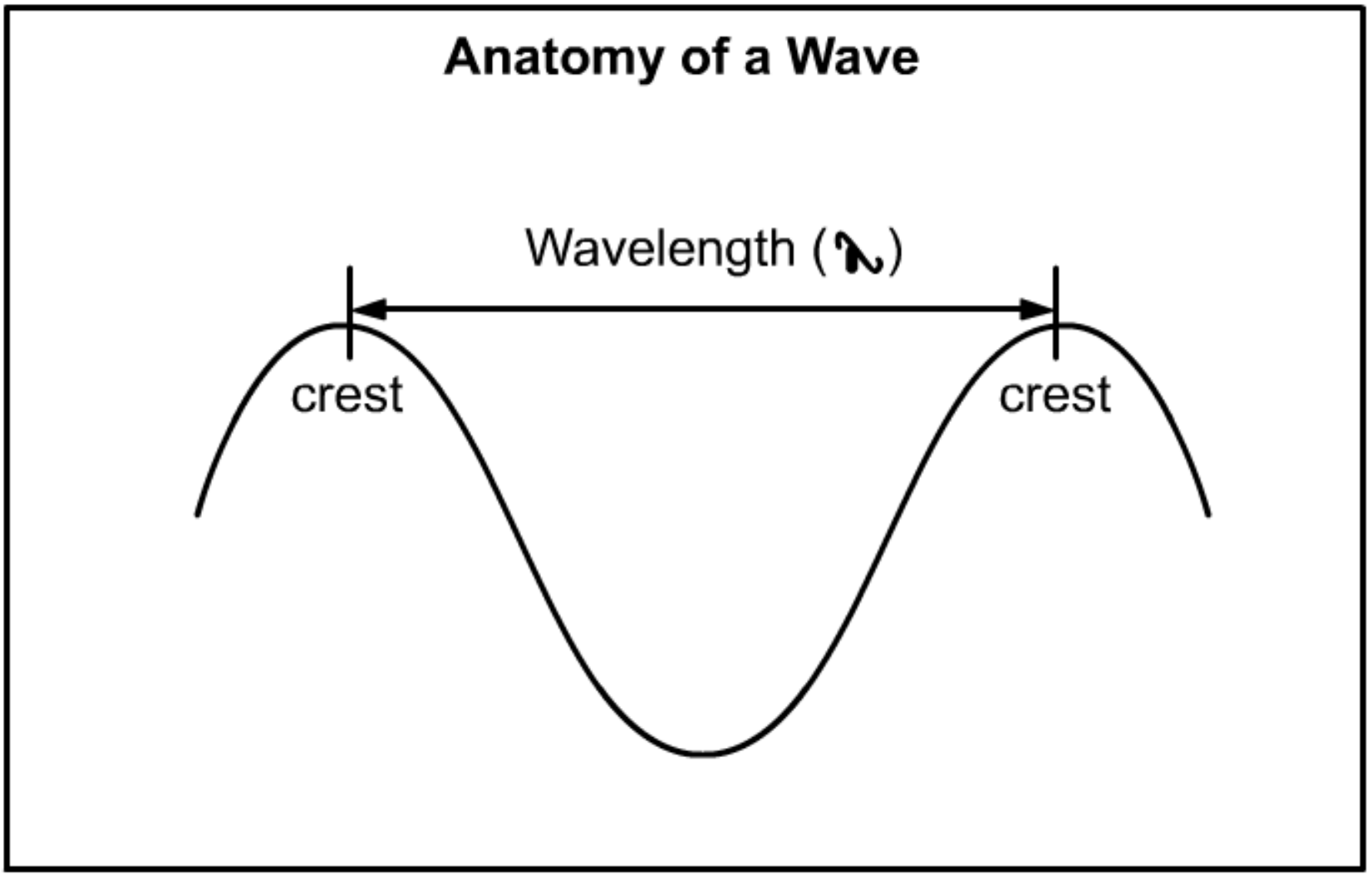
Atmospheric Physics II

4d. Determine the method of heat transfer acting in the atmosphere.

Radiation Principles

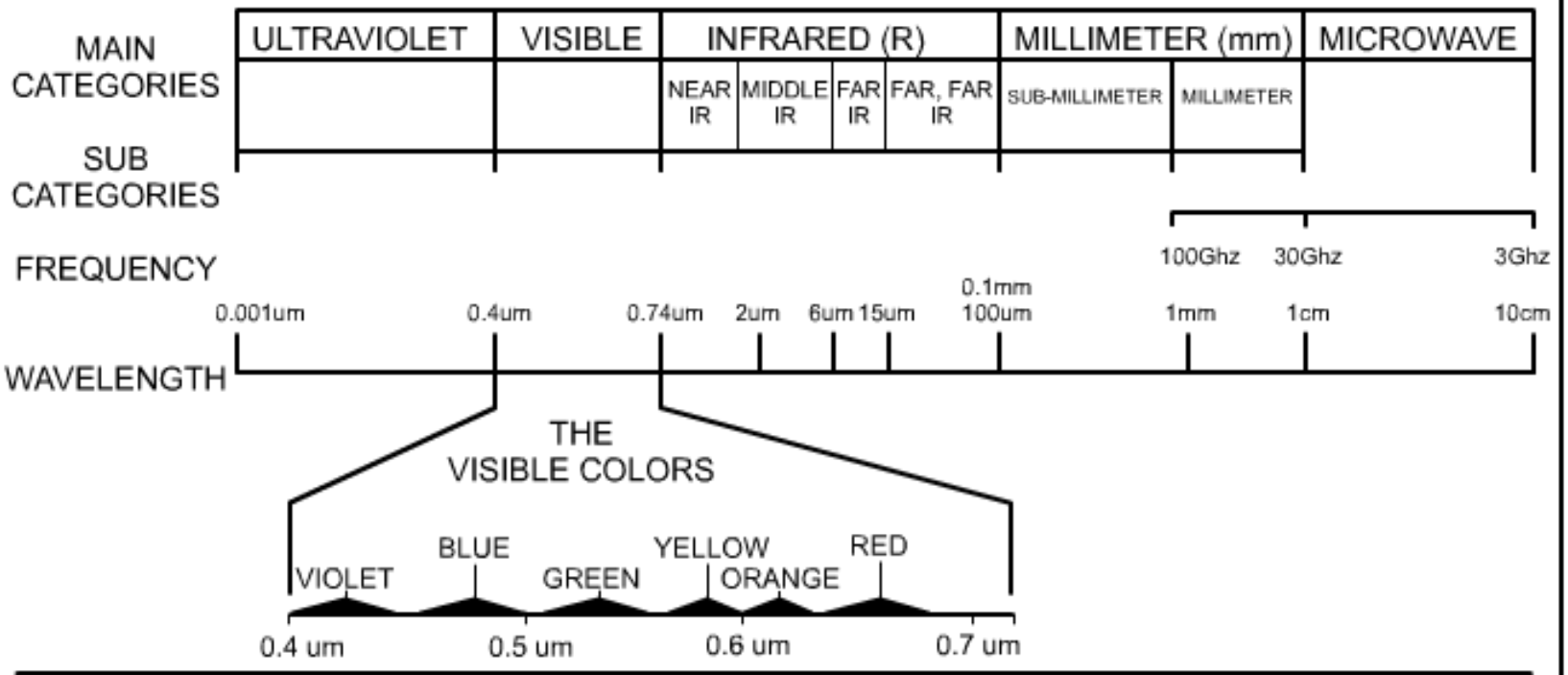
- Radiation is the transfer of energy by electromagnetic waves (the waves have electrical and magnetic properties).
- Characteristics of waves
  - Wavelengths are measured from crest to crest.
  - Wavelength is symbolized by the Greek symbol lambda (λ).


Anatomy of a Wave
Wavelength (λ)
crest
crest

Radiation Principles

- Electromagnetic Radiation
  - The electromagnetic spectrum is a complete range of wavelengths going from radio waves at one end of the spectrum to gamma rays at the other end.
  - Wavelengths important to weather
    - Shorter wavelengths emitted by the sun (UV and Vis)
    - Longer wavelengths emitted by the earth (Vis, IR)

ELECTRO-MAGNETIC SPECTRUM



Symbol definition: 1Hz = 1 Hertz = 1 cycle/sec: 1Ghz = 1 Gigahertz = 10^{9} Hz:
1cm = 1/100 meter = 10^{-2} meter: 1mm = 1/1000 meter = 10^{3} meter:
1um = 1 micrometer = 1/1,000,000 meter = 10^{6} meter.
Frequency - Wavelength relationship: $S = f.\lambda$ where
S = speed of light (2.997×10^{10} cm/sec), f = frequency (Hz), λ = wavelength

Radiation Principles

- Blackbodies
  - Any object that has a temperature above absolute zero emits and radiates electromagnetic radiation.
  - Blackbodies:
    - Are “ideal” objects and are perfect absorbers and emitters.
    - Absorbs all radiation which hit them and emits all possible radiation.
  - Real objects (gray bodies) are selective absorbers as they absorb and emit only selected wavelengths.

Radiation Principles

- Definitions
  - Emissive power is the energy radiated from a surface area per unit time.
  - Emissivity is the ratio of the observed object's radiant emission to that of an ideal blackbody at a specific wavelength and temperature.

    Example: Infrared satellite imagery represents radiant energy emitted from the earth and its atmosphere at a specific wavelength.The satellite sensor measures the earth's emissivity by detecting radiant energy emitted by the earth's surface and atmosphere (e.g., clouds). absorbed emissive power to that of a blackbody.

Radiation Principles

- Definitions
  - Absorptivity is the fractional part of the incident radiation that is absorbed by the surface. It is a measure of how efficiently an object absorbs energy.
  - Reflectivity is the fractional part of the incident radiation that is reflected by a surface.
  - Transmissivity is the fractional part of the radiation allowed to pass unobstructed through a medium per unit of thickness along the path of the radiant beam.

Radiation Principles

- Definitions
  - Scattering is when radiation encounters very small objects (such as dust and air molecules) and is deflected in all directions.

Radiation Principles

- Radiation laws
  - Kirchoff's law
    - This law states that good absorbers are good emitters at a particular wavelength and poor absorbers are poor emitters at the same wavelength.
    - The earth’s surface and the sun approach being blackbodies.

Radiation Principles

- Radiation laws
  - Planck's Law
    - This law describes the amount of energy emitted by a blackbody at a specific temperature for each wavelength of the electromagnetic spectrum.
    - This law says the higher the temperature, the greater the emissive power.

Radiation Principles

- Radiation laws
  - Stefan-Boltzmann Law
    - This law states that the amount of radiation emitted by an object is proportional to the fourth power of its surface temperature. ($E = \sigma T^4$)
    - Earth vs sun
      - The sun is approximately 20 times warmer than the earth (using Kelvin scale).
      - How much more solar radiation will the sun emit?

Radiation Principles

- Radiation laws
  - Wien's Law states that as you increase an object's temperature, the wavelength at which it emits most of its energy decreases

    Max wavelength = 3000/T (°K)
    - Example: λ_{max} the sun vs. the earth. If the sun's temperature is 6,000° K therefore: 3,000/6,000 = .5 µm Earth's average temperature 300° K, 3,000/300 = 10 µm. Hence, the lower the temperature, the longer the wavelength.

Radiation Principles

- Incoming solar radiation
  - Energy from the sun is short-wave radiation because the sun is hotter than the earth and emits shorter wavelengths of radiation.
  - These fall mainly in the ultraviolet and visible portions of the electromagnetic spectrum.

Radiation Principles

- Scattering is the process by which molecules or larger particles diffuse a portion of the electromagnetic spectrum.
  - A major source of attenuation of radiation in the atmosphere.
    - The shorter the wavelength, the more scattering will occur.
    - Atmospheric particles affect the propagation of radiation.

Radiation Principles

- Attenuation occurs when radiation traveling through the atmosphere decreases in intensity as it moves further from the emitting surface.
  - Attenuation occurs due to absorption and scattering by atmospheric constituents.
  - The further the energy travels through the atmosphere, the more attenuation that takes place. But the amount of attenuation is highly dependent on wavelength and atmospheric conditions.

Radiation Principles

- Types of scattering
  - Rayleigh / Molecular Scattering
    - » Occurs when the size parameter (x) is much less than one micrometer (< 1 µm). Specifically, this type of scattering occurs when atmospheric particles are less than one-tenth the wavelength of the incident radiation.
    - » Is caused by atmospheric molecules and particles scattering a portion radiation in of the EMR spectrum.
    - » The sky is blue wavelengths of blue light are more prone to atmospheric scattering than any other wavelengths in the visible spectrum.
    - » The least amount of atmospheric scattering expected.

Radiation Principles

- Types of scattering
  - Mie / Aerosol Scattering (Forward Scattering)
    - » Occurs when size parameter is greater than 1 micrometers and will ease when it approaches 10 μm.
    - » Caused by atmospheric aerosols.
    - » Is directional in nature, forward scattering predominates.
  - Geometric scattering (Back scattering)
    - » Happens when relative humidity is over 90%.

Radiation Principles

- Absorption is the process by which incident radiant energy is retained by a substance.
  - Gases are selective absorbers, meaning that they absorb strongly in some wavelengths, moderately in others, and only slightly in still others.
  - Substances tend to absorb in specific wavelength intervals called absorption bands

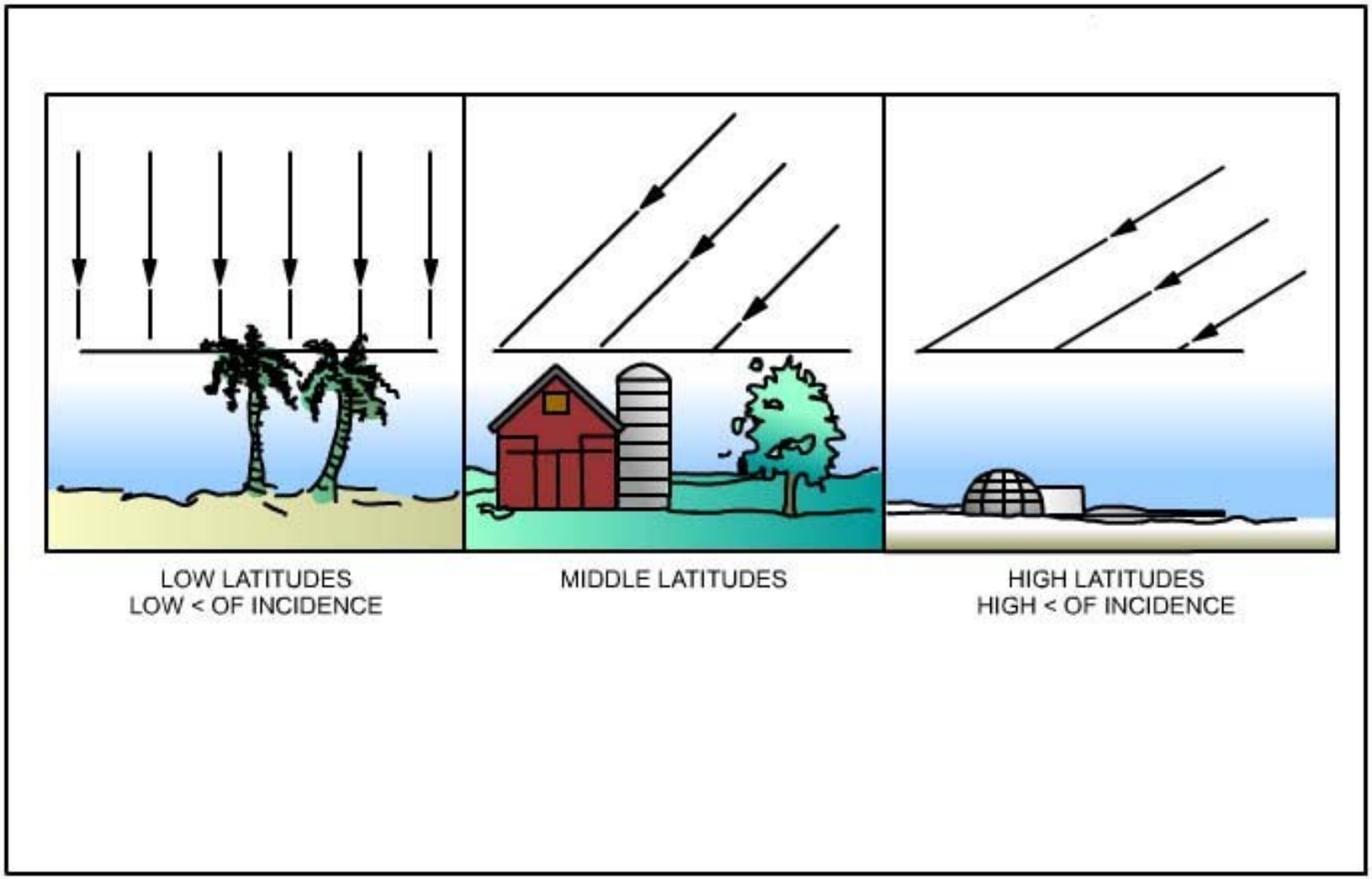
    For instance, ozone absorbs radiation at very short ultraviolet wavelengths (<0.4 µm)
  - Atmospheric window - a large “gap” between 8 and 11µm in which none of the gases are effective absorbers of radiation.

Radiation Principles

- Continuum Absorption - absorption varies slowly with wavelength, across broad regions of the electromagnetic radiation (EMR) spectrum.
  - » Water vapor and carbon dioxide are some of the most significant absorber for wavelengths > 1 µm.
  - » For example, an increase in the concentration of water vapor increases absorption, use both relative and specific humidity.
  - » Specific humidity is a measure of the actual amount of water in the air, while relative humidity indicates how close the air is to saturation.
  - » During the afternoon, desert areas may have low relative humidity but high absolute humidity.

Radiation Principles

- Angle of incidence is the angle at which the sun's rays strike the earth's surface.
  - Dependent on latitude.
  - Smaller angles near the equator result in a larger concentration of heating per unit of area (i.e., more radiant energy per unit area).
  - Larger angles near the poles result in a smaller concentration of heating per unit of area. (i.e., less radiant energy per unit area).


LOW LATITUDES
LOW < OF INCIDENCE
MIDDLE LATITUDES
HIGH LATITUDES
HIGH < OF INCIDENCE

Radiation Principles

- Reflection is the process whereby a surface turns back or repels incident radiation into the medium through which it came.
  - Occurs with a size parameter greater than ten micrometers.
  - Reflectance is a measure of radiant energy reflected from an object.
  - Albedo is the ratio of the amount of radiation reflected by a surface to the amount of the radiation incident on the surface.
    - » The albedo represents the value as a decimal and the reflectivity is in percent.
    - » Albedo = $\frac{\text{reflected ray}}{\text{incident ray}}$

Radiation Principles

» Reflectivity = $\frac{\text{reflected ray}}{\text{incident ray}}$ x 100 %

Radiation Principles

- Radiant energy is only converted to sensible heat energy when it is absorbed. Radiant energy must be absorbed by a surface or substance in order for sensible heat to be realized.
- A substance, which is a good reflector, is a poor absorber because less radiation is available for absorption.

Example: If a mirror and blacktop pavement lay flat and side-by-side on a sunny summer day at 12 noon, a large temperature difference would develop between two surfaces. The mirror would reflect most incident sunlight away.; thus the minimal absorption would lead to only a small increase in temperature. However, the blacktop would absorb much greater amounts of radiation and therefore would experience a significant increase in temperature

Radiation Principles

- Terrestrial radiation

  As earth eats up due to absorption of shortwave radiation, the earth must the try to cool itself through the loss of longwave (i.e., terrestrial) radiation to space.
  - Energy emitted by the earth is long-wave radiation because the cooler temperatures of the earth and its atmosphere.
  - These fall primarily in the infrared portion of the electromagnetic spectrum.

Radiation Principles

- Greenhouse effect
  - Carbon Dioxide (CO_2) and water vapor in the troposphere strongly absorb most of the long-wave radiation emitted from the earth's surface.
  - These substances then re-emit the long-wave radiation in all directions. (Including back towards the ground).
  - A portion of this re-radiated energy reaches the surface of the earth and is reabsorbed by the ground (heating it).
  - This causes the surface temperature to be greater than if no water vapor or CO_2 existed in the atmosphere.

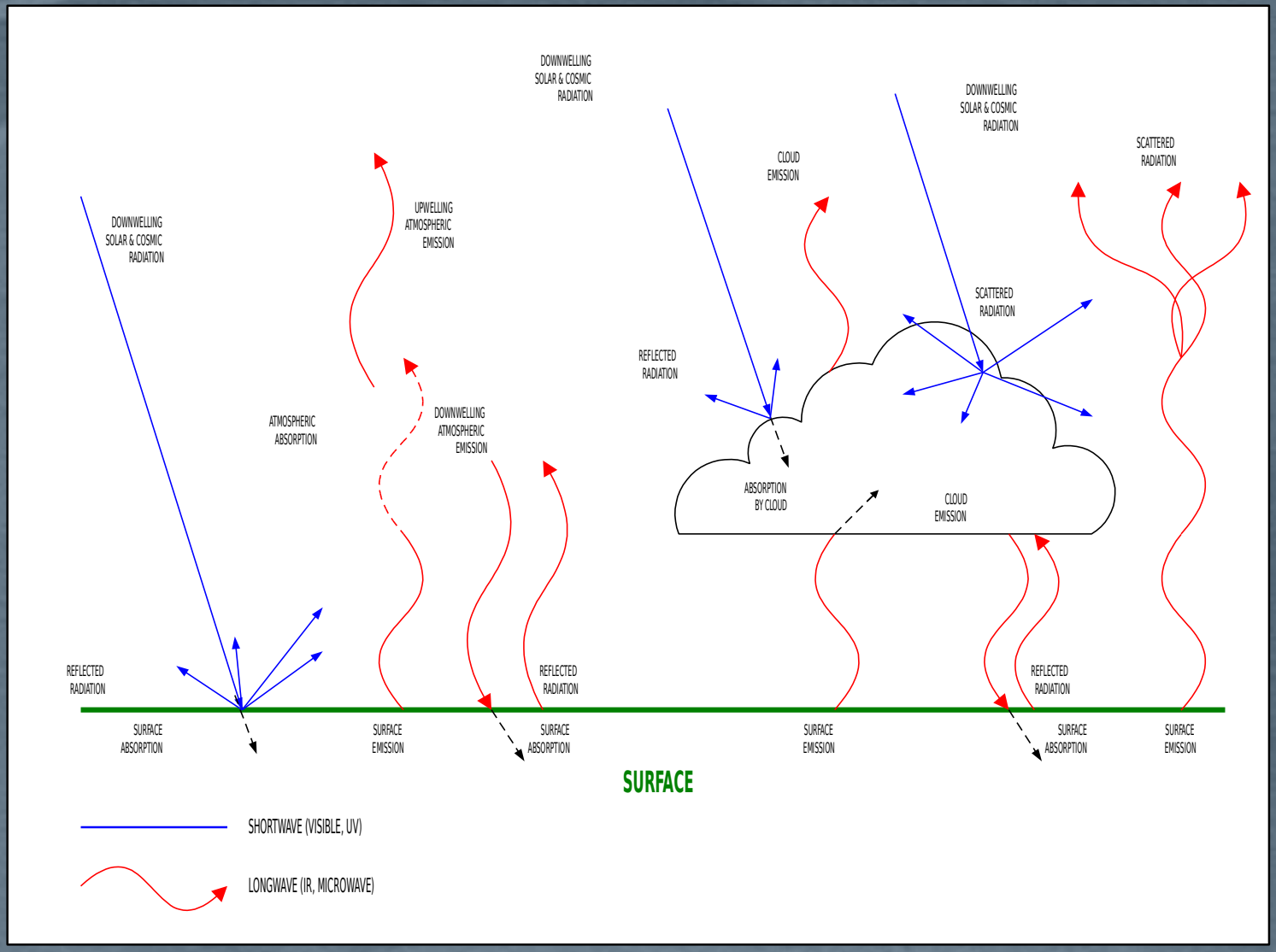
Radiation Principles

- The absorption varies with the wavelength of the radiation. Some long-wave radiation passes through the atmosphere and out to space.
- CO_2 and water vapor absorb very little radiation with wavelengths of 8μm - 11μm.
- This range is called the Atmospheric Window since most radiation in these wavelengths passes freely through the atmosphere and is radiated out to space.

Radiation Principles

Radiation Budget

– Solar radiation enters the top of atmosphere.
  - Clouds reflect a certain amount.
  - The atmosphere absorbs some.
  - The atmosphere scatters some.
  - The rest makes it through to the surface of the earth where a portion is reflected, and the rest is absorbed.


DOWNWELLING SOLAR & COSMIC RADIATION
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UPWELLING ATMOSPHERIC EMISSION
CLOUD EMISSION
SCATTERED RADIATION
SCATTERED RADIATION
REFLECTED RADIATION
ATMOSPHERIC ABSORPTION
DOWNWELLING ATMOSPHERIC EMISSION
ABSORPTION BY CLOUD
CLOUD EMISSION
REFLECTED RADIATION
REFLECTED RADIATION
REFLECTED RADIATION
SURFACE ABSORPTION
SURFACE EMISSION
SURFACE ABSORPTION
SURFACE EMISSION
SURFACE ABSORPTION
SURFACE EMISSION
SURFACE
SHORTWAVE (VISIBLE, UV)
LONGWAVE (IR, MICROWAVE)

Radiation Principles

- Terrestrial (longwave) radiation leaving the surface of the earth.
  - Terrestrial radiation is emitted by the surface of the earth.
    - Some is absorbed by the atmosphere and re-emitted in all directions.
    - The atmosphere radiates some.
    - A certain amount makes it through to the top of the atmosphere and is emitted to outer space.

Conduction

- Conduction is the transfer of energy by molecular motion.
- Transfer of heat is always from hot to cold.

Conduction

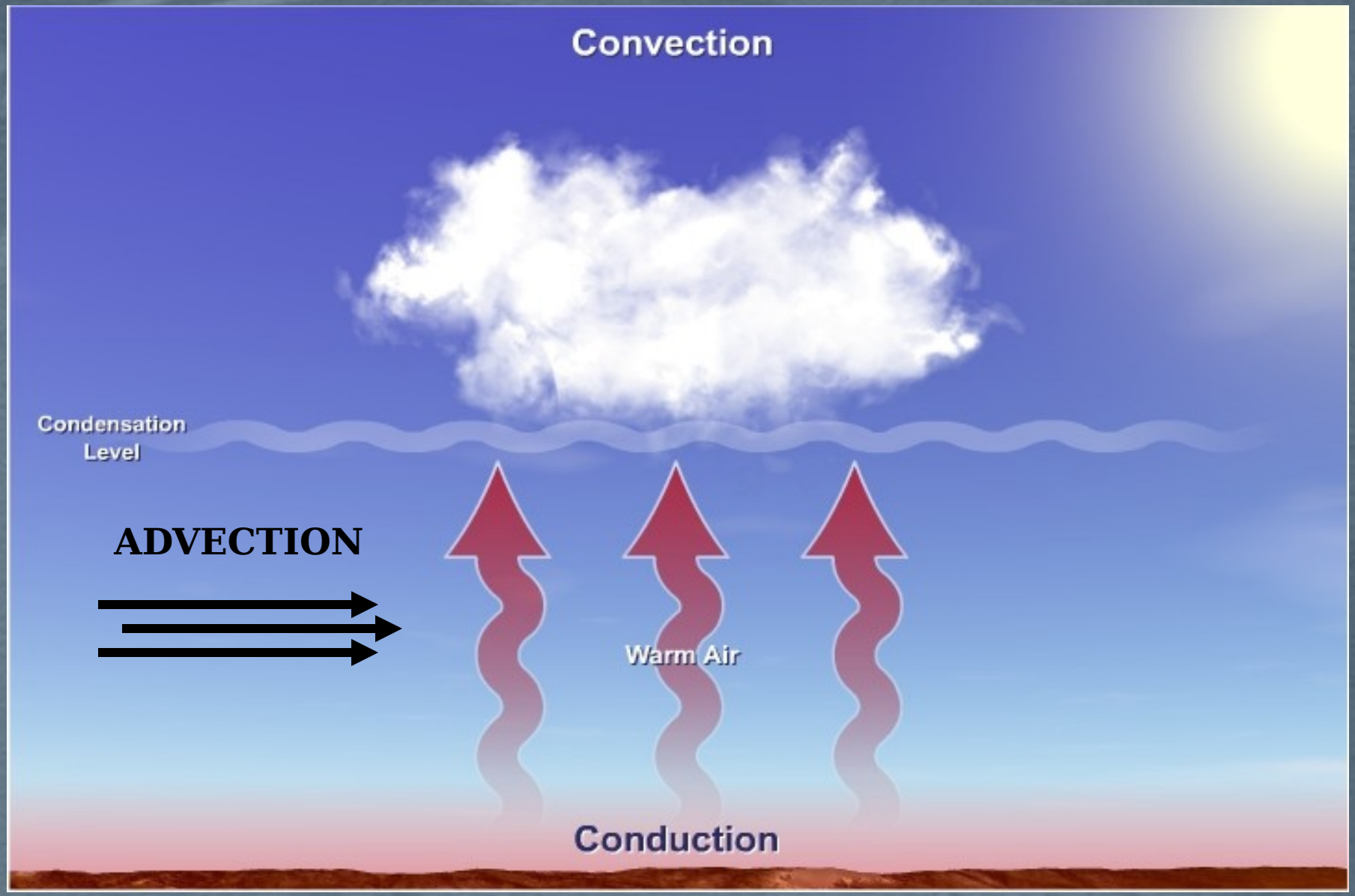
- Heat conductivity is the ability of a substance to conduct heat. (Related to molecular structure (heat capacity) and density of a substance).
  - Air is a poor conductor of heat.
  - Soil is approximately 10 times better and water is approximately 100 times better than air.
  - Because air is a poor conductor, conduction is important as a heat transfer mechanism only at the surface of the earth.

Conduction

- Atmospheric significance
  - The surface of the earth heats and cools by absorption and emission of radiation.
  - Conduction links the surface to the air directly above it. Influences
    - » Low-level stability.
    - » Air-mass modification.
  - Conduction is important in transferring heat between the surface and the atmosphere but dominates only in the molecular boundary layer. (More in objective h.)
  - Other mechanisms (convection, advection) must act to transport heat to and from other places, vertically or horizontally in the atmosphere.

Convection

- Convection is the vertical transport of atmospheric properties (heat and moisture).
- More efficient method of heat transfer than conduction.


Convection
Condensation Level
ADVECTION
Warm Air
Conduction

Convection

- Associated with upward vertical motion which can be initiated by
  - Surface heating
  - Low-level convergence
  - Orographic effects
  - Frontal lift and other methods of forcing convection are introduced in Dynamics (i.e., upper air forcing).

Convection

- The vertical extent of convection is influenced by the stability of the atmosphere.
  - A stable atmosphere suppresses convection.
  - An unstable atmosphere enhances convection.
- Much of the moisture at upper levels of the atmosphere is transported upward by convection.
- Convection occurs in the troposphere (the stable stratosphere acts to "cap" convection).

Advection

- Advection is the horizontal transport of atmospheric properties.
- Temperature advection deals with the horizontal transport of heat and moisture.
- Moisture advection deals with the horizontal transport of water vapor.

- APPLICATION: Assign Review Exercises in WB-100
- EVALUATION: Administer and evaluate Appraisal 104d. Give the written test at the end of the unit.